

SUBWOOFER WITH CASCADED LINEAR ARRAY OF DRIVERS**BACKGROUND OF THE INVENTION****[001] 1. Technical Field:**

[002] The invention relates to an electro-acoustical device and, more particularly, to a folded horn loudspeaker for reproducing low frequency audible sound at high output levels from electric-acoustic transducers having relatively small diaphragms.

[003] 2. Description of the Problem:

[004] The reproduction of low frequency audible sound, with high fidelity and at high intensity levels, poses a number of challenges. To do so from a small, energy efficient package, portable enough to be moved and suitable for open air use is especially difficult. Generally, high output, high efficiency, low frequency loudspeakers have been built around a horn. A horn is in effect an acoustic transformer, allowing the designer to obtain the output performance of a driving unit having a large area diaphragm from a unit having a smaller area diaphragm while minimizing cone/diaphragm resonance issues that exist with direct radiator devices. Increasing the effective diaphragm area renders radiation impedance increasingly resistive with the result that increasing power is radiated at the desired low frequencies. However, increasing acoustic power output from most horn designs has required increasing diaphragm piston travel in order to move the required volume velocity of air. Piston travel becomes an important limiting factor relating to the amount of power that can be delivered to the horn.

[005] Another limitation on the total energy input that can be introduced to a horn has been the limited scalability of horns. Though examples of multiple driver horns are known, typically only a single driving unit for a given frequency range has been provided. One example of a multiple driver horn (United States Patent 5,898,138) positions a pair of low frequency transducers having throats located equidistant from the horn's mouth. While effective such an arrangement is still not readily scalable.

SUMMARY OF THE INVENTION

[006] According to the invention there is provided a folded, expanding horn loudspeaker

having a selectable plurality of acoustic drivers for a given frequency range. The loudspeaker unit provides a compact enclosure defining the folded, expanding horn and housing the acoustic drivers. A scalable number of identical acoustic drivers is provided, each having a relatively small cone or diaphragm, and each being located in a sealed back chambers (i.e. a closed box baffle). The acoustic drivers radiate into volumetrically identical high pressure chambers located in front of the drivers. The acoustic drivers are preferably positioned with respect to one another in a linear array and may vary in number from 2 to 12. Each high pressure front chamber is coupled to a summing throat for the horn by an extended port which operates as a air pressure or air volume velocity step up transformer. The outlets of the ports are acoustically spaced from one another and differentially spaced from the mouth of the horn. Transducer drive circuitry applies drive signals to the acoustic transducers derived from a common source. The signals to the respective acoustic transducers are delayed to reflect the distance of the throats for the respective acoustic transducers from the mouth of the horn. The source signal is also as filtered and phase adjusted as required for clear reproduction of the sound.

[007] Additional effects, features and advantages will be apparent in the written description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[008] The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

[009] **Fig. 1** is a perspective view of a loudspeaker enclosure;

[0010] **Fig. 2** is a perspective view of the loudspeaker horn.

[0011] **Fig. 3** is a cross sectional view of the loudspeaker enclosure of **Fig. 1** taken along section line 3--3.

[0012] **Fig. 4** is a cross sectional view of the loudspeaker enclosure of **Fig. 1** taken along section line 4--4.

[0013] Fig. 5 is a cross section of a transducer housing taken along section line 5--5 in Fig. 3.

[0014] Fig. 6 is a rear elevation of the enclosure of Fig. 1 with the back panel of the enclosure removed.

[0015] Fig. 7 is a block diagram schematic of drive circuitry for the loudspeaker.

[0016] Fig. 8 is a block diagram schematic of the operation of the circuitry of Fig. 7.

[0017] Fig. 9 is a side elevation of a high pressure chamber exited by paired drivers.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Referring now to the figures and in particular to Fig. 1 there is illustrated a loudspeaker system 10 for use as a high output, transportable unit. Loudspeaker system 10 comprises a right trapezoid enclosure or cabinet 11 which houses sound radiators and a folded waveguide or horn having a mouth 12 in front wall 14. Mouth 12 directs sound radiated from loudspeaker system 10 forward from the unit. Enclosure 11 is constructed from front wall 14, a back wall, a first side wall 16, a second side wall (described below), a cover 18 and a base 20. The bases and walls are conventionally made of plywood or some other material which does not readily absorb sound.

[0019] Referring to Fig. 2, enclosure 11 is presented in phantom at a reverse angle from the view of Fig. 1. Folded horn 22 is optimized for low frequency use and is constructed from flat sides and incorporates a flair, as is conventional. Folded horn 22 is disposed along side walls 16, 17 and the back wall 15 of enclosure 11 which form portions of the horns walls. Folded horn 22 expands cross-sectionally along its entire length from a base end 161, adjacent which the horn has its minimum cross-sectional area, to end 163 where the mouth of the horn is located. Folded horn 22 expands initially both vertically and horizontally, but eventually only in the horizontal dimension. A summing throat 61 is disposed along side 17 which expands in both the vertical and horizontal directions to a fold 151, where it matches with a first backside section 121. Backside section 121 continues to expand in two mutually perpendicular directions up to a second backside section 123. Section 123 is characterized by horn 22 having a constant vertical dimension, however expansion continues in the horizontal dimension at a rate consistent with the horn's flair constant. Vertical expansion is stopped in second backside section 123 not for functional reasons, but for external packaging reasons. Section 123 meets the final horn section

125, which continues to expand in the horizontal dimension, along fold **153**. Loudspeakers are nestled in the pocket **200** formed by and partially enclosed by the exterior faces of folder horn **22**.

[0020] Fig. 3 is a cross sectional view of enclosure **11** taken along section line 3-3 in Fig. 1. Four walls form the perimeter, exterior sides of enclosure **11** including front wall **14**, first side wall **16**, back wall **15** and a second side wall **17**. The perimeter formed by these walls is broken only by mouth **12** which provides a radiating outlet from the waveguide, i.e. folded, expanding horn **22**. Folded horn **22** comprises four major sections and two bends or folds and, as described above, a rectangular cross sectional shape. A horn flare is provided by increasing the area of the section with distance through the horn **22**. Initially, the cross-sectional dimensions of folded horn **22** increase in both the vertical and horizontal dimensions, but eventually only in the horizontal. Folded horn **22** includes a summing throat **61** into which four ports or extended throats **58**, **60**, **62** and **64** are directed. Folded horn **22** expands both vertically and horizontally for the entire length of summing throat **61**. Folded horn **22** is divided into two sections **121** and **123** along back wall **15** of enclosure **11**. Section **121** continues the two dimensional cross sectional expansion of fold horn **22** from summing throat **61**. Section **123** expands only horizontally. Running from section **123** to mouth **12** is the final horn section **125**, which also expands only in the horizontal direction.

[0021] Four acoustic drivers or transducers **26**, **28**, **30** and **32** are positioned in enclosure **11** (the latitudinal positions of which are illustrated in phantom) and oriented to direct sound downwardly into four high pressure (or preload) chambers **34**, **36**, **38** and **40** located directly above base **20**. The upper surface of base **20** forms the bottom surfaces of high pressure chambers **34**, **36**, **38** and **40** which are aligned with one another. Acoustically absorbent pads **42**, **44**, **46** and **48** are positioned on the upper surface of bottom board **20** within each of chambers **34**, **36**, **38** and **40** to deaden resonance. Pads **42**, **44**, **46**, **48** correspond to and are vertically aligned with acoustic drivers **26**, **28**, **30**, **32**, respectively. High pressure chambers **34**, **36**, **38** and **40** have acoustic outlet ports formed by extended throats **58**, **60**, **62** and **64**, respectively. Extended throats **58**, **60**, **62** and **64** direct energy into summing throat **61**. The outlets from extended throats **58**, **60**, **62** and **64** act as diaphragms aligned along one side of the summing throat **61** of folded throat **22**. These outlets are at different distances from mouth **12** and, as a consequence, see different output impedances and have different propagation times for the sound energy they emit to mouth **12**. The phase and frequency response of horn **22** will differ with respect to extended throats **58**, **60**, **62** and **64**, sometimes in ways difficult to predict in advance for particular horn parameters and thus empirical evaluation may be required to determine the best dynamic phase adjustments, frequency band widths and roll offs to be used with the drive signal for

each of the acoustic drivers **26, 28, 30** and **32**. High pressure chambers **34, 36, 38, 40** each have the same volume as one another and the throats **58, 60, 62** and **64** have the same cross sectional areas as one another.

[0022] Each extended throat **58, 60, 62** and **64** has a cross sectional area which is at least 20% of the area of diaphragm for the corresponding acoustic drivers **26, 28, 30** and **32** and 100% of that area. of the corresponding diaphragms. Preferably the diaphragms of drives **26, 28, 30** and **32** are each about 3-1/2 times the area of the cross section of the extended throats. As the diaphragms move back and forth in alternating fashion to form compression waves in the air mass, the air in high pressure chambers **34, 36, 38** and **40** varies in pressure. The extended throats are relatively constricted in area when constructed the preferred ratio and function as pneumatic amplifiers increasing the volume velocity of the air. Accordingly the movement of driver diaphragms **326, 328, 330, 332** can be made much smaller than is the case on the prior art because changes in air pressure in high pressure chambers **58, 60, 62** and **64** are relatively stiff. At the same time, the high pressure compression chambers **58, 60, 62** and **64** absorb much more power per unit of movement of the diaphragm allowing much larger driver motors **226, 228, 230** and **232** to be employed than in prior art devices. These motors may be two to three times as powerful as is conventional, for example, a 6-inch woofer may be driven by a ____ watt drive coil. For maximum power input diaphragm **326, 328, 330** and **332** may be pushed at velocities up to the point of destructive turbulence in the extended throats **58, 60, 62** and **64**.

[0023] The high pressure chambers, back chambers, extended throat and summing throat **61** are formed in part by vertical interior walls supported from base **20**. Vertical interior wall **33** provides a portion of one side of folded horn **22** adjacent mouth **12** opposite the side provided by first exterior side wall **16**. Vertical interior wall **33** and side wall **16** diverge from one another toward mouth **12** to provide an expanding cross-sectional area for horn **22**. Vertical side wall **33** also provides an interior wall for each of extended throat **58, 60, 62, 64** and for front chambers **34, 36, 38** and **40**. The horizontal perimeter of preload or high pressure chamber **34** is completed by vertical walls **25, 41** and **70**. The horizontal perimeter of high pressure chamber **36** is completed by vertical walls **27, 41** and **72**. The horizontal perimeter of high pressure chamber **38** is completed by vertical walls **29, 41** and **74**. The horizontal perimeter of high pressure chamber **40** is completed by vertical walls **31, 41** and **76**. Wall **41** is broken in three places by outlets from throat extension guides **61, 62** and **64**. The horizontal perimeters of high pressure chambers **34, 36, 38, 40** are broken by throats **50, 52, 54, 56**. The horizontal perimeter of throat extension section **58** is completed by vertical walls **14** and **70**. The horizontal perimeter of throat extension section **60** is completed by vertical walls **25** and **72**. The

horizontal perimeter of throat extension section **62** is completed by vertical walls **27** and **74**. The horizontal perimeter of throat extension section **64** is completed by vertical walls **29** and **76**. Vertical walls **33**, **50**, **72**, **74** and **76** all continue upwardly to provide perimeter elements of substantially sealed back chambers (or closed-box baffles) for acoustic drivers **26**, **28**, **30** and **32**.

[0024] Referring to **Fig. 4**, which is a cross sectional view taken along section line **4--4** in **Figs. 1** and **2** and to **Fig. 5**, which is view taken into enclosure **11** along section line **5--5** in **Fig. 4**, the positioning of acoustic drivers **26**, **28**, **30**, **32** over high pressure chambers **34**, **36**, **38** and **40** is illustrated. Acoustic drivers **26**, **28**, **30**, **32** are housed in sealed back chambers **80**, **82**, **84** and **86**, respectively. The term "sealed" as used here has its conventional meaning in the acoustical arts to mean that the back chambers have no acoustic outlet port. The only acoustic opening from sealed back chambers **80**, **82**, **84** and **86** are those directly in front of the diaphragms of acoustic drivers **26**, **28**, **30** and **32**. Back chambers **80**, **82**, **84** and **86** do slowly exchange air with their ambient environment, as is conventional.

[0025] In **Fig. 5** the position of extended **60** in front of wall **72** illustrates the interface of a representative high pressure chamber **36** to its extended throat **60** and further into summing throat **61**. Because the upper cover section **91** is not horizontal, but slants upwardly from the base of summing throat **61** toward the back wall **15**, the outlet from extended throats into summing throat **61** differs for each extended throat. Extended throat **60** includes some freeboard on wall **41** above the outlet and below upper cover section **91**. As illustrated in **Fig 6** and described with reference to the figure below, the amount of freeboard for each port will differ. Acoustic driver **28** rests on a support plane **93**. Sealed back chamber **82**, like the remaining back chambers, is closed on one side by a planer wall **95**.

[0026] Referring now to **Fig. 6**, which is an end view of enclosure **11** with back wall **15** removed, the interior of folded horn **22** is illustrated in greater detail, particularly the summing throat **61**. Summing throat **61** is formed by portions of side wall **17**, cover **91**, base **18** and wall **41**. Summing throat **61** collects sound output from the four throat extension sections **58**, **60**, **62**, **64**, the radiating outlets of which are visible along a side of summing section **61** defined by vertical wall **41**. The surfaces forming summing throat **61** diverge from one another moving toward the back wall **15** from the base of the horn along front wall **14**. The divergence of the upper and lower surfaces of folded horn **22** is provided in the upward slant of board **97**. While the output port from extended throat **58** has a vertical extent substantially equal to the local height of summing throat **61**, the outlets of downstream extended throats **60**, **62** and **64**, which are all of the same height, will have increasing amounts of freeboard.

[0027] Any given horn has differing horizontal and polar frequency responses. And while a horn may operate well at certain frequencies its performance can degrade markedly at other frequencies. These changes in performance are highly dependent on the length of the horn. While each of transducers **26, 28, 30, 32** is coupled to the folded horn by an identical high pressure chamber and extended throat, the extended throats in **56, 60, 62** and **64** are coupled to summing junction **61** at points which are differently spaced from the mouth **12**. In other words, horn **22** will have different performance characteristics for each transducer including, different optimal frequency operating range. Accordingly, each driver circuit differentially treats the signal applied to each transducer.

[0028] Producing sound of maximum intensity from loudspeaker system **10** requires that acoustic pressure waves from the outlets of extended throats be synchronized at the points where they merge. Due to the different distances sound travels to reach mouth **12** from the outlets from extended throats **58, 60, 62** and **64**, the drive signal applied to transducers **26, 28, 30, 32** is time differentiated so that the sound waves constructively reinforce one another in summing section **61** rather than cancel or interfere with one another. While the same signal is the genesis of the signal used to drive each of the four transducers **26, 28, 30, 32**, this source signal must be processed differently before application to the respective transducers' voice coils to assure good phase matching at the mouth **12** and a good match of output from the extended throats **58, 60, 62** and **64** to the frequency response characteristic of folded horn **22** for a given outlet port from one of extended throats **58, 60, 62** and **64**. The signal for the transducer associated with the throat radiating end removed by the greatest distance from mouth **12** is delayed least, while the signal driving the transducer associated with the throat radiating end closest to mouth **12** is delayed by the greatest period. Differences in impedance matching of the extended throat for each driver to summing section **61** require some band pass filtering and shading of the source signal for optimal system performance. The source signal may require dynamic phrase adjustment (i.e. adjustment of the signal phase as a function of frequency) of the source signal due to the frequency response characteristics of the horn which vary with frequency at each extended throat outlet port.

[0029] Referring to **Figs. 7** and **8**, a common source **711** of audio frequency signals is applied to four inputs of a digital signal processor (DSP) **709** which differentially processes the signals to accommodate the relative positions of acoustical drivers **26, 28, 30, 32**. DSP **709** provides the four differentiated outputs on each of four channels **713, 715, 717, 719** to four amplifiers **701, 703, 705** and **707** associated with acoustical drivers **26, 28, 30, 32**. In general, the input signal is processed in the same general way for all four channels, with only the parameters applied by the processing steps

changing. For each channel, the signal is fed through a band pass filter **801** which passes frequency ranges best handled by a particular horn/driver configuration. Typically, the broadest band of frequencies is applied to the acoustic driver couple to the summing junction **61** at the furthest point from mouth **12**. The roll off of the signal range applied to a driver may also be adjusted. Next, the filtered signal is applied to a time delay **803** which synchronizes the signals based on the differing distances of the speakers from the horn mouth. Lastly, the filtered, delayed signal for a channel is applied to a dynamic phase adjustment module **805**, which adjusts the phase of the signal as a function of frequency. The specific parameters used will change along with changes in horn dimensions and the number of transducers used.

[0030] Fig. 9 illustrates an alternative embodiment of the invention whereas two acoustic drivers **930A** and **930B** are coupled to a common high pressure chamber **900**. Sound is coupled from compression chamber **900** to a horn **922** by an extended throat **902** which has a cross sectional area which is a fraction of the area of the diaphragms of acoustic drivers **930A-B**. Extended throat **902** operates as a kind of pneumatic amplifier greatly accelerating air velocity. Still other arrangements of transducers and horn types will now occur to those skilled in the art.

[0031] The invention provides high acoustic output power for low frequency sound from a minimally sized, portable cabinet, suitable for use at outdoor, temporary venues. The package is well suited for bass line reproduction required for rock music reproduction.

[0032] While the invention is shown in only one of its forms, it is not thus limited but is susceptible to various changes and modifications without departing from the spirit and scope of the invention.